

Geochemical Speciation of Metal Ions in the Leachate of Tailings Treated with Synthetic Rain Water

Elvis Fosso-Kankeu*, Brad Barlow, Nico Lemmer and Frans Waanders

Abstract—Prediction of the possible mobilization of metals from tailings and their speciation is necessary for implementation of site specific management strategies. In this study 11 different tailings samples were collected near the city of Krugersdorp at an abandoned mine tailings dam. Samples from the top, middle and bottom of the tailings were assessed for twelve consecutive weeks through means of column leaching experiments. The parameters analysed for assessment of speciation of metal pollutants were pH, electrical conductivity (EC), oxidation redox potential (ORP), alkalinity, acidity, major anions (sulphate, chloride). Mineralogical- and chemical characterization of the tailings sample were conducted using X-ray diffraction (XRD) and X-ray fluorescence (XRF) respectively. Metal analysis was performed by means of inductively coupled plasma optical emission spectroscopy (ICP-OES). Speciation of metal ions was conducted through the use of PHREEQC modelling software. The main objective of this study was to determine the impact of acid rain on the mobility of metals in the tailings. XRD results showed that the bottom and middle of the tailings are dominated by quartz whilst the top was found to be dominated by alunite. The XRF results showed that the major oxide minerals were SiO_2 , Fe_2O_3 and Al_2O_3 . The ICP analyses showed that Ca and Na were most likely to leach from the tailings; the major metal pollutants leached were Al, Ca, Fe, Mg, Mn and Na. Synthetic acid rain had more effects on the metal mobility and the oxidation of mineral sulphides compared to samples treated without the acid rain. pH levels varied slightly from treated- and control samples. The PHREEQC results showed that the heavy metals tend to form free ionic species with samples treated with synthetic acid rain, consequently increasing the bioavailability of the heavy metals and therefore the toxicity levels in water bodies exposed to tailings.

Keywords— Mine tailings, metal mobility, synthetic acid rain water, ORP, pH, synthe Sulphate, XRD, XRF

I. INTRODUCTION

Abandoned mine tailings pose a threat to the environment when toxic heavy metals leach into the ground layer below as a result of acid mine drainage (AMD) [1 - 8]. AMD occurs primarily when pyrite is exposed to oxygen. This oxygenation process degrades the quality of exposed surface water and lower

its pH values [1]. Acid mine drainage in South Africa occurs primarily from active and abandoned mine tailings exposed to rain and other weather conditions. The process starts as oxygenated rain water falls on the

Exposed mine tailings, causing oxidation of pyrite (FeS_2) to occur [10 - 12]. The pyrite undergoes oxidation in a two-stage process, the first producing sulphuric acid and ferrous sulphate and the second orange-red ferric hydroxide and more sulphuric acid. The sulphuric acid then percolates through the tailings and dissolves the heavy metals in transit making these heavy metals increasingly soluble. Effectively these heavy metals emerge from the base of the tailings dump to add to the local ground water as a pollution plume [13]. The degree of mobilization of metals from tailing dumps by acid rain is influenced by the nature or properties of the tailing dumps; implying that the deriving environmental impact will be site specific. It is therefore important to predict the possible mobilization of metals from a given tailing in order to implement proper management strategy for the mitigation of pollution. Mobilization and dispersion of heavy metals as a result of AMD influenced by normal rainfall (pH 5.6) have been studied. It is the effects of acidic rainfall (4.0 - 4.6pH [14]) on exposed mine tailings that is of environmental concern. Prior to oxidation sulphuric- and nitric acid is present within the water molecules of acidic rain. The addition of sulphuric acid prior to oxidation of pyrite increases the overall concentration of sulphate within the tailings dam which could consequently increase the solubility and with that the bioavailability of heavy metals within the tailings [15]. In addition the speciation of metals within the tailings may tend to differ from normal rainfall conditions, this will affect the dispersion as it is dependent on the speciation of metals. Consequently if metals tend to occur mainly in the free hydrated form as opposed to complex metal form the mobility of heavy metals will increase as well as toxicity. The occurrence of metals in surface and ground waters is of concern as these can cause carcinogenic effects and toxicity in aqueous system and to people using such waters [16 - 27]. The purpose of this study is to determine the impact of acidic rainfall on the *mobility* of heavy metals within the tailings as well as to effectively determine the potential of the *dispersion* of metals released from the tailings.

Elvis Fosso-Kankeu is with the School of Chemical and Minerals Engineering of the North West University, Bult area-Potchefstroom-South Africa

Frans Waanders is with the School of Chemical and Minerals Engineering of the North West University, Bult area-Potchefstroom-South Africa

Brad Barlow is with the School of Chemical and Minerals Engineering of the North West University, Bult area-Potchefstroom-South

II. EXPERIMENTAL SETUP AND MODELLING

A. Materials

Soil samples were collected at a depth between 0-30 cm, using an auger drill, from abandoned gold mine tailings near Krugersdorp in the province of Gauteng, South Africa. A total of eleven samples were collected at different elevations of the tailings dam to ensure variations in the sampled soil. The soil samples (from each layer) were then mixed together to form three complex samples representing the top, centre and bottom of the tailings. Samples were then dried using heating ovens at 110 °C for a period of 3 hours. Samples were then stored in tight seal plastic containers before use.

B. Mine Tailings Characterization

Characterization of the mine tailings was conducted by determining the chemical- and mineralogical composition as well as the particle size distribution (PSD) of the representative samples for the top, centre and bottom of the tailings dam. Prior to analysis, 40 g of the samples representing each layer were weighed off and then crushed to a particle size of 75 µm. The mineralogical composition was then determined using a Philips X'Pert pro MPD X-ray diffractometer for the X-ray diffraction (XRD) analyses. The chemical composition was determined using a MagiX Pro & Super Q X-ray Fluorometer for X-ray fluorescence spectrometry (XRF). The particle size distribution for each representative layer was determined using Malvern Master-sizer equipment.

C. Synthetic Acid Rain Production

Before soil samples could be packed in the leaching columns synthetic acid rain was produced using 98% sulphuric acid and 55% nitric acid. The solution used for the production of synthetic acid rain was in a 3:2 mL ratio of sulphuric acid to nitric acid. An aliquot of the acid solution was added to 100 mL distilled water which was used as a buffer solution to produce synthetic acid rain by adding 4 mL of the buffer solution to 500 mL of distilled water till a pH value of 4.2 was observed using a Hanna instruments 8424 pH meter. This experiment was repeated until 8 L of synthetic acid rain was produced.

D. Column Leaching Experiments

The physicochemical parameters were analysed for a twelve week column leaching period. Twelve columns were used to conduct the experiment in triplicate for each representative layer. The remaining three columns were used for control samples. The columns were each packed with 800 g sample mixed with 300 mL synthetic rain water and distilled water for control samples beforehand. Each sample was then topped up to 10 cm above the packed material. The leachate of each column was then measured weekly for pH, temperature, electron conductivity (EC) and oxidation redox potential. A pH meter

with an analytical electrode (HI8424) was used for pH, temperature and ORP measurements. A conductivity meter with an electrode was used to measure the EC. Sulphate concentration was measured monthly with a COD and Multiparameter Photometer HI 83099. The leachate of each sample was thrown back at the top of the column after measurements were noted.

E. Titration Tests

The acidity was measured through titration method with 0.02 N sodium hydroxide (NaOH) where 0.02 N sodium carbonate (Na₂CO₃) was used as standardization procedure. The alkalinity on the other hand was measured through titration method with 0.1 N sulphuric acid (H₂SO₄). For chloride ion concentration, titration was conducted using silver nitrate (AgNO₃) and potassium dichromate (K₂CrO₄) as indicator.

F. Metal Analyses

To analyse the metal concentration, 3 mL of each sample was first stored in the fridge at 4°C, then 1 mL of each sample was diluted by a dilution factor of 10 using distilled water and then stored in a lab fridge prior to analysis. Metal analysis was then conducted using inductively coupled plasma-optical emission spectrometry (ICP-OES).

G. Speciation Modelling

To determine the aqueous speciation of the major metal ions in the leachate of tailings, AQUACHEM software was used interfaced with PHREEQC (program version 3.136-9191.) modelling software. For the purpose of this report the database Minteq.v4.dat was used. Before the input data could be used the ORP had to be calculated by adjusting with a correction factor obtained from Field Measurements of Oxidation-Reduction Potential [28], this value is then used to calculate the pe value using the following equation:

$$pe = E_h / (0.059) \quad (1)$$

pe denotes the negative logarithm of the electron activity.

E_h denotes the oxidation redox potential of the sample.

The following input data was then used for speciation calculation: pH, Eh (pe), temperature and determined concentration of metals, Cl⁻ and SO₄²⁻.

III. RESULTS AND DISCUSSION

A. Particle Size Distribution

The particles size distribution for each representative layer is displayed in Fig. 1, Fig. 2 and Fig. 3. As is evident from the results the particle sizes from the bottom and the top of the tailings dumps range from 1 µm to 1000 µm. However the result obtained for the middle of the tailings indicate that the particle sizes range between 1 µm and 400 µm. Smaller particles have larger surface areas than larger particles, thus a larger area is left

exposed to the effects of AMD making it more likely for metals to be released in higher concentrations [29]. This indicates that metals are much more likely to leach from the middle representative sample and acidity likely to form than the other two representative layers.



Fig. 1: Particle size distribution of the bottom tailings sample

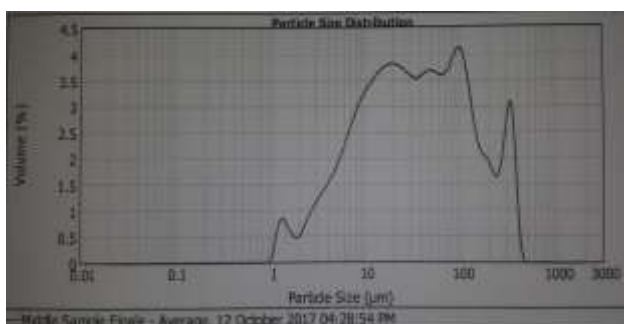


Fig. 2: Particle size distribution of middle tailings sample

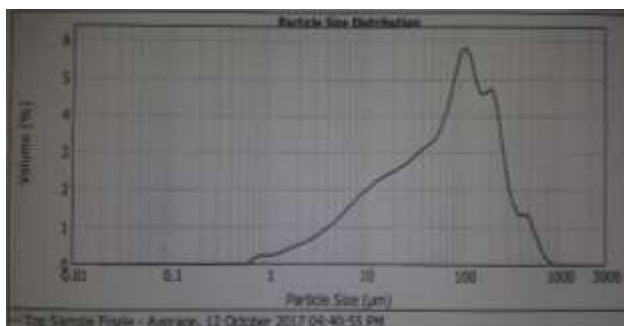


Fig. 3: Particle size distribution of top tailings sample

B. Mineralogical and Chemical Composition

TABLE 1:
MINERALOGICAL COMPOSITION OF TAILINGS SAMPLES

Minerals	Weight % in sample layers		
	Bottom	Middle	Top
Quartz	77.60	84.87	-
Coesite	15.58	-	30.26
Iron Sulphide	0.17	4.92	-
Hematite	-	5.30	-
Aluminite	-	-	39.63
Aluminum Iron	-	-	27.68
Rozenite	-	-	1.56

XRD analyses were performed to evaluate the mineralogical composition of the representative tailings samples. The XRD results show that the bottom and middle of the tailings

comprised mainly of quartz. Other mineral such as amaranite, coesite, hematite and gypsum were also present. The top of the tailings was mainly comprised of aluminite coesite and aluminum iron.

An XRF analyses is preformed to evaluate the chemical composition of the representative tailings samples. The XRF results determined that the dominant oxide present in each tailings sample is SiO₂. The other dominant oxides were identified as Al₂O₃, CaO, Fe₂O₃, K₂O and SO₃.

TABLE 2: CHEMICAL COMPOSITION OF TAILINGS SAMPLES

Samples	Mass & in sample layers					
	Al ₂ O ₃	SiO ₂	SO ₃	K ₂ O	CaO	Fe ₂ O ₃
Bottom	6.50	81.32	2.94	0.70	1.10	6.44
Middle	8.97	70.62	1.36	0.73	0.43	16.61
Top	9.08	84.50	1.50	0.45	0.71	2.74

C. pH Results

Fig. 4 shows the overall change in pH levels for each of the representative layers over the 12 week leaching period. The control samples, which were treated with distilled water, are displayed as BC, MC and TC for bottom-, middle- and top control samples respectively. The experiments were conducted in triplicate and the average values for the bottom (BS), middle (MSI) and top (TS) samples treated with synthetic acid rain were used for analysis as the standard deviation for these samples fell within the 10% margin.

Acidic condition was observed for the bottom and middle of the tailings with pH values of 2 and 3 whilst the top representative layer displayed alkaline conditions with pH values between 7 and 8.

The experimental results and control for each representative layer displayed the same behaviour as the trends are relatively the same. Although the bottom is dominant in sulphate concentrations as seen in **Error! Reference source not found.**, the oxidation rate tends to be very slow as the pH values of the bottoms samples (BC & BS) displays an almost constant trend as a slight decrease was observed over the 12 week period.

The pH values for the middle representative layer tends to vary as an increase in pH for both MC and MS from weeks 1 to 4 is observed. Buffering is dominant for the middle samples (MC and MS) until oxidation occurs as pH value decreases from weeks 5 to 12, first at a very slow rate and then sudden increase is observed between weeks 9 and 12.

The pH levels for the top of the tailings sample shows a constant increase for the 12 weeks leaching period, this can be due to the high concentration of Ca and Mg, observed through ICP analyses of metal ions, which contributes to an increase in pH [30]. This also corresponds with the increase in alkalinity measured for the top tailings sample over the 12 weeks period.

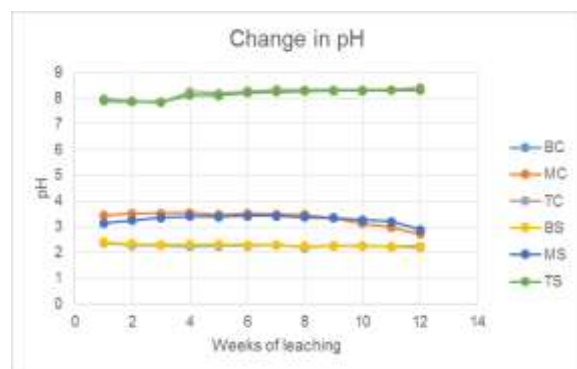


Fig. 4: Change in pH levels

D. Speciation Results

The five major heavy metal pollutants were analysed for the leachate of tailings treated with synthetic acid rain and for the control samples using PHREEQC workbench software. The workbench software effectively calculates and reports the speciation of the heavy metal pollutants in terms of their free hydrated ions and inorganic complexes [31]. These results are important as inorganic complexes tend to decrease the concentration of free aqua metal ionic species. Effectively this leads to a decrease in bioavailability and with it a decrease in toxicity levels. The PHREEQC results are displayed in Table 3. The dominant species of iron in the bottom and middle representative layers were in the free hydrated form of Fe^{+2} ranging from 49.96-78.93% for synthetic rain samples and 55.13-64.23% for control samples. The top tailings layer was also dominated by the free hydrated species $\text{Fe}(\text{OH})_2^{+}$. Complex hydroxide and carbonate species are also present ($\text{Fe}(\text{OH})_4^-$ and FeHCO_3^+) but at very low concentrations. Due to the high amount of free ions, iron is easily able to disperse in surface water causing an increase in toxicity. Magnesium was mainly comprised of the free ionic species Mg^{+2} and the complexed species MgSO_4 . Other complex carbonate species of Mg are also present (MgHCO_3^+ and MgCO_3) but to a low extent. The speciation modelling predicted that manganese would mostly be soluble as a free ion species Mn^{+2} with a percentage range 58.29-82.56% for species treated with synthetic acid rain and 62.96-70.51% for the control samples. Manganese was also available in high concentrations of the complex species MnSO_4 . Nickel was most abundant as a free hydrates species (Ni^{+2}) for the acidic rain samples and as a complex ion (NiSO_4) for the control samples. Other species of Ni predicted were NiCl^+ and the carbonate species NiCO_3 . Zinc follows the same trend as Ni with the acidic rain samples being more abundant as a free ionic species (Zn^{+2}) and the control samples as a complex species ($\text{Zn}(\text{SO}_4)_2^{-2}$). The free ionic species were the greatest for samples treated with synthetic acid rain. Thus for tailings exposed to acidic rainfall with the addition of acids prior to oxidation increases the bioavailability of metallic species within the tailings consequently increasing the toxicity levels in ground

water as these heavy metal species are mobilized from the tailings dumps.

TABLE 3: SPECIATION RESULTS FOR MAJOR HEAVY METAL POLLUTANTS IN THE LEACHATE OF TAILINGS

Element	Species	%Range for synthetic rain samples	%Range for control samples
Fe(2)	Fe^{+2}	49.96-78.93	55.13-64.23
	FeSO_4	21.31-48.89	38.34-44.88
	FeOH^+	0.21-1.06	0.39-0.82
	FeHCO_3^+	<1	<1
	$\text{Fe}(\text{OH})_2^+$	0-81.5	0-77.03
Fe(3)	$\text{Fe}(\text{OH})_3$	0-54.13	0-31.25
	$\text{Fe}(\text{OH})_4^-$	0-12.74	0-13.44
	FeOH^{+2}	<1	<1
	Mg^{+2}	30.9-78.67	36.06-61.38
Mg	MgSO_4	21.33-69.13	39.29-63.90
	MgHCO_3^+	<1	<1
	MgCO_3	<1	<1
	MgOH^+	<1	<1
Mn(2)	Mn^{+2}	58.29-82.56	62.96-70.51
	MnSO_4	15.89-41.33	28.32-37.29
	MnCl^+	0-1.5	0.11-1.17
	MnCl_2	<1	<1
	NiSO_4	22.04-69.52	40.89-64.98
Ni	Ni^{+2}	28.34-72.18	33.44-57.61
	NiCl^+	0.32-3.85	0.52-3.19
	NiCO_3	0-2.65	0.98-3.88
Zn	$\text{Zn}(\text{SO}_4)_2^{-2}$	2.59-69.57	11.36-74.46
	ZnSO_4	13.17-40.61	17.29-39.64
	Zn^{+2}	4.91-71.24	8.16-49.60

IV. CONCLUSION

The PSD results for the tailings samples shows that the particles tend to be present in larger sizes in the top and bottom of the tailings (1-1000 μm) whilst the middle representative layer contained smaller samples in the range 1-400 μm . The data analyses of the physicochemical parameters shows that there is a difference between the measured values of the leachate of the tailings treated with synthetic acidic rain water and distilled water (control). The pH levels for the top and bottom of the samples displayed almost identical results with slight variations. The middle tailings samples had larger variation to the control samples. The pH is lower for the samples treated with synthetic acid rain. PHREEQC results showed that heavy metals in the tailings treated with synthetic acid rain were abundant in the free ionic form which enhances the mobility of these metals contributing to increased levels of pollution. Control samples were more mostly contained the complex form, however some free ionic species were also predicted.

ACKNOWLEDGMENT

The authors are grateful to the sponsor from the North-West University and the National Research Foundation in South Africa. Any opinion, findings and conclusions or recommendations expressed in this material are those of the authors and therefore the NRF does not accept any liability in regard thereto. The authors appreciate the contribution of Mr E.

Malenga and Ms N. Baloyi from the University of Johannesburg in South Africa; Mr G. Van-Rensburg from the North-West University.

REFERENCES

- [1] Fosso-Kankeu E, Mulaba-Bafubiandi A, Mamba BB, Barnard TG. 2009. Mitigation of Ca, Fe, and Mg loads in surface waters around mining areas using indigenous microorganism strains. *Journal of Physics and Chemistry of the Earth*, Vol 34, pp 825-829.
- [2] Fosso-Kankeu E, Mulaba-Bafubiandi A, Mamba BB, Barnard TG. 2011. Assessing the effectiveness of a biological recovery of nickel from tailings dumps. *Journal of Minerals Engineering*, Vol 24, pp 470-472.
- [3] A.H. Munyai, E. Fosso-Kankeu, F. Waanders. 2016. Biological influence on the mobility of metals from mine tailing dump located in Krugersdorp area. *International Journal of Science and Research*. ISSN: 2319-7064. 5(4): 1396-1403.
- [4] Munyai AH, Fosso-Kankeu E, Waanders F. 2016. Mobility of metals from mine tailings using different types of organic acids: Batch leaching experiment. *International Journal of Science and Research*. 5: 520-527.
- [5] Fosso-Kankeu E., Mulaba-Bafubiandi, A.F., Mamba, B.B., Marjanovic L. and Barnard T.G. 2009. Optimising the removal by *B. subtilis* and *B. bacterium* of metals found around mining areas: evaluation of the effect of physical and physiological parameters. In: *Water Institute of Southern Africa & International Mine Water Association: Proceedings, International Mine Water Conference*. International Mine Water Association Conference, Pretoria 2009. ISBN: 978-0-9802623-5-3.
- [6] Elvis Fosso-Kankeu, Frans B. Waanders, and Ashley H. Munyai. 2015. Susceptibility of Metals Release from Tailings Dumps Located In the Krugersdorp Area. 7th International Conference on Latest Trends in Engineering and Technology (ICLTET' 2015), November 26-27, 2015 Irene, Pretoria (South Africa). Editors: E. Muzenda and T Yingthawornsuk. ISBN: 978-93-84422-58-5.
- [7] Elvis Fosso-Kankeu, Frans Waanders, and Wiehan Botes. 2015. Recovery of Base Metals from Mine Tailings Dumps collected in the Vicinity of Potchefstroom: Leaching assisted by Complexing Agent. 7th International Conference on Latest Trends in Engineering and Technology (ICLTET' 2015), November 26-27, 2015 Irene, Pretoria (South Africa). Editors: E. Muzenda and T Yingthawornsuk. ISBN: 978-93-84422-58-5.
- [8] Munyai AH, Fosso-Kankeu E, Waanders F. 2016. Effects of organic acids on heavy metals released from mine tailings. *International Conference on Advances in Science, Engineering, Technology and Natural Resources (ICASETNR-16)* Nov. 24-25, 2016, Parys – South Africa. ISBN: 978-93-84468-79-8.
- [9] Hoffert, J. R. (1947). *Acid Mine Drainage*. In *Industrial and Engineering Chemistry* (pp. 642-646). Harrisburg.
- [10] Elvis Fosso-Kankeu, Alusani Manyatshe, Frans Waanders. 2017. Mobility potential of metals in acid mine drainage occurring in the Highveld area of Mpumalanga Province in South Africa: Implication of sediments and efflorescent crusts. *International Biodeterioration and Biodegradation*. 119: 661-670.
- [11] Fosso-Kankeu, E., Manyatshe, A., Munyai, A., Waanders, F., 2016. AMD formation and dispersion of inorganic pollutants along the main stream in a mining area. In: Drebenstedt, C. & Paul, M.: *IMWA 2016 – Mining Meets Water – Conflicts and Solutions*. – p. 391 – 397; Freiberg/Germany (TU Bergakademie Freiberg).
- [12] Fosso-Kankeu E. 2016. Investigation of the oxidation rate of sediments from AMD using humidity cell test. *International Conference on Advances in Science, Engineering, Technology and Natural Resources (ICASETNR-16)* Nov. 24-25, 2016, Parys – South Africa. ISBN: 978-93-84468-79-8.
- [13] McCarthy, T. S. (2011). *The impact of acid mine drainage in South Africa*. Johannesburg: S Afri J Sci.
- [14] Hairston, J., Shaw, J., Brantley, E., & Beck, J. (2003). *Acid Rain: An Overview*.
- [15] Smith, K., & Huyck, H. (1999). *An Overview of the Abundance, Relative Mobility, Bioavailability, and Human Toxicity of Metals*. Society of Economic Geologists Inc McCarthy, T. S. (2011). *The impact of acid mine drainage in South Africa*. Johannesburg: S Afri J Sci.
- [16] E. Fosso-Kankeu, AF Mulaba-Bafubiandi, BB Mamba and TG Barnard. 2011. Prediction of metal-adsorption behaviour in the remediation of water contamination using indigenous microorganisms. *Journal of Environmental Management*, 92 (10), pp 2786-2793.
- [17] E. Fosso-Kankeu, AF Mulaba-Bafubiandi. 2014. Implication of plants and microbial metalloproteins in the bioremediation of polluted waters. *Journal of Physics and Chemistry of the Earth*. 67-69: 242-252.
- [18] E. Fosso-Kankeu, AF Mulaba-Bafubiandi. 2014. Challenges in the escalation of metal-biosorbing processes for water treatment: applied and commercialized technologies. *African Journal of Biotechnology*. 13(17): 1756-1771.
- [19] E. Fosso-Kankeu, F. Waanders, E. Maloy. 2016. Copolymerization of ethyl acrylate onto guar gum for the adsorption of Mg(II) and Ca(II) ions. *Desalination and Water Treatment*. doi: 10.1080/19443994.2016.1165147: 1-10.
- [20] E. Fosso-Kankeu, A.F. Mulaba-Bafubiandi, L.A. Piater, M.G. Tlou. 2016. Cloning of the *cnr* operon into a strain of Bacillaceae bacterium for the development of a suitable biosorbent. *World Journal of Microbiology and Biotechnology*. DOI 10.1007/s11274-016-2069-5.
- [21] Alusani Manyatshe, Elvis Fosso-Kankeu, Divan van der Berg, Nico Lemmer, Frans Waanders, Hlanganani Tutu. 2017. Metal retention potential of sediment and water quality in the Mooi River, South Africa. *Desalination and Water Treatment*. doi: 10.5004/dwt2017.20222.
- [22] Elvis Fosso-Kankeu, Frans B. Waanders, Frederik W. Steyn. 2017. Removal of Cr(VI) and Zn(II) from an aqueous solution using an organic-inorganic composite of bentonite-biochar-hematite. *Desalination and Water Treatment*. 59: 144-153.
- [23] A. Manyatshe, E. Fosso-Kankeu, D. van der Berg, N. Lemmer, F. Waanders, H. Tutu. 2017. Dispersion of inorganic contaminants in surface water in the vicinity of Potchefstroom. *Physics and Chemistry of the Earth*. 100: 86-93.
- [24] F. Waanders, M. Nel, E. Fosso-Kankeu. 2014. Adsorption potential of bentonite clay and attapulgite applied for the desalination of sea water. 6th International Conference on Green Technology, Renewable Energy and Environmental Engineering (ICGTREEE'2014). 27-28 November 2014, Cape Town-South Africa. Editors: Muzenda E. and Sandhu S. ISBN: 978-93-84468-08-8. Pp 275-279.
- [25] Fosso-Kankeu E, Waanders F, Reitz M. 2014. Selective adsorption of heavy and light metals by natural zeolites. 6th International Conference on Green Technology, Renewable Energy and Environmental Engineering (ICGTREEE'2014). 27-28 November 2014, Cape Town-South Africa. (**Award Winning Paper**). Editors: Muzenda E. and Sandhu S. ISBN: 978-93-84468-08-8. Pp 271-274.
- [26] Elvis Fosso-Kankeu, Frans Waanders, Antoine F. Mulaba-Bafubiandi and Sibusiso Sidu. 2015. Leachability of suspended particles in mine water and risk of water contamination. 10th ICARD/IMWA 2015; 10th International Conference on Acid Rock Drainage & IMWA Annual Conference. 21-24 April 2015 Santiago-Chile. Editors: Adrian Brown, Charles Bucknam, Joanna Burgess, Manuel Carballo, Devin Castendyk, Linda Figueroa, Lisa Kirk, Virginia McLemore, James McPhee, Mike O'Kane, Robert Seal, Jacques Wiertz, David Williams, Ward Wilson, Christian Wolkersdorfer. ISBN: 978-956-9393-28-0. Chap 4. Pp 1-9.
- [27] Elvis Fosso-Kankeu, Frans. B. Waanders, Frederik W. Steyn. 2015. The Preparation and Characterization of Clay-Biochar Composites for the Removal of Metal Pollutants. 7th International Conference on Latest Trends in Engineering and Technology (ICLTET' 2015), November 26-27, 2015 Irene, Pretoria (South Africa). Editors: E. Muzenda and T Yingthawornsuk. ISBN: 978-93-84422-58-5.
- [28] Striggov, B. (2013). *Field Measurements of Oxidation-Reduction Potential (ORP)*.
- [29] Munyai, A. (2017). Investigation of the effect of microorganisms and their metabolites on the mobility of metals in a gold tailing dump in South Africa.
- [30] WHO. (2011). *Guideline for drinking-water quality* (4th ed.)
- [31] Manyatshe, A., Fosso-Kankeu, E., Berg, D. v., Lemmer, N., Waanders, F., & Tutu, H. (2017). Metal Speciation in the Rivers Around Potchefstroom Based on Seasonality. *Water Environmental Research*.

The corresponding author is currently an Associate Professor in the School of Chemical and Minerals Engineering at the North-West University (Potchefstroom). He is an NRF rated researcher who has published journal articles, book chapters and book.

Prof Elvis Fosso-Kankeu has been the recipient of several merit awards